National Institute of Standards & Technology

Certificate

Standard Reference Material 4415H, Lot 29
Xenon-133 Radioactivity Standard

This Standard Reference Material (SRM) consists of radioactive xenon-133 gas and non-radioactive xenon gas. The gas is contained in a flame-sealed borosilicate-glass ampoule. The SRM is intended for the calibration of ionization chambers and solid-state gamma-ray spectrometry systems.

Radiological Hazard

The SRM ampoule contains xenon-133 with a total activity of approximately 12 GBq. Xenon-133 decays by beta-particle emission. None of the beta particles escape from the SRM ampoule. During the decay process, X rays and gamma rays, with energies from approximately 4 keV to 384 keV, are emitted. Most of these photons escape from the SRM ampoule and can represent a radiation hazard. Appropriate shielding and/or distance should be used to minimize personnel exposure. The SRM should be used only by persons qualified to handle radioactive material.

Chemical Hazard

The SRM ampoule contains only unpressurized xenon gas. The xenon gas is not a chemical hazard

Storage and Handling

The SRM should be stored and used at a temperature between 5 and 65 °C. The gas in an unopened ampoule should remain stable and homogeneous until at least September 2006. The ampoule (or any subsequent container) should always be clearly marked as containing radioactive material. If the ampoule is transported it should be packed, marked, labeled, and shipped in accordance with the applicable national, international, and carrier regulations. The gas in the ampoule is a dangerous good (hazardous material) because of the radioactivity.

Preparation

This Standard Reference Material was prepared in the Physics Laboratory, Ionizing Radiation Division, Radioactivity Group, M.P. Unterweger, Acting Group Leader. The overall technical direction and physical measurements leading to certification were provided by D.B. Golas and O.T. Palabrica, Nuclear Energy Institute Research Associates. The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the Standard Reference Materials Program.

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PROPERTIES OF SRM 4415H, Lot 29, Ampoule 1

Certified values

Radionuclide	**Xenon-133**
Reference time	**1800 EST, 22 September 2005**
Activity of the gas [a]*	**11.90 GBq**
Relative expanded uncertainty (*k*=2)	**0.78%** [b] [d]

Uncertified values

Physical Properties:		
Source description	Gas in a flame-sealed borosilicate-glass ampoule	
Gas pressure	(55 ± 11) kPa at 0 °C [c] [d]	
Ampoule specifications	Length Outside diameter Wall thickness Volume	4.5 cm 1.5 cm (0.12 ± 0.02) cm [d] 5 mL
Chemical Properties:		
Gas composition (approximate)	Chemical Formula	Amount (mol)
	Xe ^{133}Xe	1×10^{-4} 1×10^{-8}
Radiological Properties:		
Photon-emitting impurities (Activity ratios at reference time)	^{85}Kr/^{133}Xe: $(1.4 \pm 0.3) \times 10^{-6}$ [d] [e] ^{131m}Xe/^{133}Xe: $(5.7 \pm 1.4) \times 10^{-3}$ [d] [e]	
Half lives used	Krypton-85: (10.756 ± 0.018) a [f] [4] Xenon-131m: (11.84 ± 0.07) d [f] [4] Xenon-133: (5.243 ± 0.001) d [f] [4] Radium-226: (1600 ± 7) a [f] [4]	
Calibration method and measuring instrument(s)	Pressurized "4π"γ ionization chamber "A" calibrated using an ampoule of xenon-133 gas whose activity was determined using the NIST length-compensated internal gas proportional counters.	

*Notes and references are on pages 5 and 6.

EVALUATION OF THE UNCERTAINTY OF THE MASSIC ACTIVITY [b] [d]*

Input Quantity x_i, the source of uncertainty (and individual uncertainty components where appropriate)	Method Used To Evaluate $u(x_i)$, the standard uncertainty of x_i (A) denotes evaluation by statistical methods (B) denotes evaluation by other methods	Relative Uncertainty Of Input Quantity, $u(x_i)/x_i$, (%) [g]	Relative Sensitivity Factor, $\lvert\partial y/\partial x_i\rvert \cdot (x_i/y)$ [h]	Relative Uncertainty Of Output Quantity, $u_i(y)/y$, (%) [i]
PIC A net response for SRM 4415H, measured relative to RRS 5000 [j]	Standard deviation of the mean for 20 repeated measurements (A)	0.01	1.0	0.01
PIC A net response for RRS 5000, measured relative to RRS 20	Standard deviation of the mean for >100 repeated measurements (A)	0.19	1.0	0.19
PIC A net response per Bq of xenon-133, measured relative to RRS 20	Standard deviation of the mean for >100 repeated measurements (A)	0.01	1.0	0.01
Activity used to calibrate PIC A net response per Bq of xenon-133	Standard uncertainty of the activity determined using the NIST length-compensated internal gas counters (B)	0.26	1.0	0.26
Half life of xenon-133 Half life of radium-226	Standard uncertainty of the half life (A)	0.019 [k] 0.44 [k]	0.53 [m] 0.012 [m]	0.01 0.006
Photon attenuation in the ampoule	Estimated (B)	0.18	1.0	0.18
Live time [n]	Estimated (B)	0.05	1.0	0.05
PIC A charge collection	Estimated (B) [p]	0.05	1.0	0.05
Source positioning	Estimated (B)	0.10	1.0	0.10
Photon-emitting impurities	Estimated (B) [p] Estimated (B) [p] Limit of detection (B) [q]	13. 13. 100.	5×10^{-8} 0.00034 1×10^{-7}	6×10^{-7} 0.004 1×10^{-5}

Relative Combined Standard Uncertainty of the Output Quantity, $u_c(y)/y$, (%)	0.39
Coverage Factor, k	x 2
Relative Expanded Uncertainty of the Output Quantity, U/y, (%)	0.78

*Notes and references are on pages 5 and 6.

NOTES

[a] The reported value, y, of activity at the reference time was not measured directly but was derived from measurements and calculations of other quantities. This can be expressed as $y = f(x_1, x_2, x_3, . . x_n)$, where f is a mathematical function derived from the assumed model of the measurement process. The value, x_i, used for each input quantity i has a **standard uncertainty**, $u(x_i)$, that generates a corresponding uncertainty in y, $u_i(y) \equiv |\partial y/\partial x_i| \cdot u(x_i)$, called a **component of combined standard uncertainty** of y. The **combined standard uncertainty** of y, $u_c(y)$, is the positive square root of the sum of the squares of the components of combined standard uncertainty. The combined standard uncertainty is multiplied by a **coverage factor** of $k = 2$ to obtain U, the **expanded uncertainty** of y.

Since it can be assumed that the possible estimated values of the activity are approximately normally distributed with approximate standard deviation $u_c(y)$, the unknown value of the activity is believed to lie in the interval $y \pm U$ with a level of confidence of approximately 95 percent.

For further information on the expression of uncertainties, see references [2] and [3].

[b] The value of each component of combined standard uncertainty, and hence the value of the expanded uncertainty itself, is a best estimate based upon all available information, but is only approximately known. That is to say, the "uncertainty of the uncertainty" is large and not well known. This is true for uncertainties evaluated by statistical methods (e.g., the relative standard deviation of the standard deviation of the mean for the response is approximately 50%) and for uncertainties evaluated by other methods (which could easily be over estimated or under estimated by substantial amounts). The unknown value of the expanded uncertainty is believed to lie in the interval $U/2$ to $2U$ (i.e., within a factor of 2 of the estimated value).

[c] 55 kPa = 0.54 atm. = 413 Torr.

[d] The stated uncertainty is two times the standard uncertainty.

[e] Estimated limits of detection for photon-emitting impurities, based on measurements performed on October 31, 2005 and December 1, 2005 (+39 days and +70 days from the reference time) expressed as photon emission rates, are:
80 s^{-1} for energies between 40 keV and 90 keV, and
11 s^{-1} for energies between 90 keV and 3600 keV,
provided that the photons are separated in energy by 4 keV or more from photons emitted in the decay of xenon-133.

[f] The stated uncertainty is the standard uncertainty. See reference [4].

[g] Relative standard uncertainty of the input quantity x_i.

[h] The relative change in the output quantity y divided by the relative change in the input quantity x_i. If $|\partial y/\partial x_i| \cdot (x_i/y) = 1.0$, then a 1% change in x_i results in a 1% change in y. If $|\partial y/\partial x_i| \cdot (x_i/y) = 0.05$, then a 1% change in x_i results in a 0.05% change in y.

[i] Relative component of combined standard uncertainty of output quantity y, rounded to two significant figures or less. The relative component of combined standard uncertainty of y is given by $u_i(y)/y \equiv |\partial y/\partial x_i| \cdot u(x_i)/y = |\partial y/\partial x_i| \cdot (x_i/y) \cdot u(x_i)/x_i$. The numerical values of $u(x_i)/x_i$, $|\partial y/\partial x_i| \cdot (x_i/y)$, and $u_i(y)/y$, all dimensionless quantities, are listed in columns 3, 4, and 5, respectively. Thus, the value in column 5 is equal to the value in column 4 multiplied by the value in column 3. The input quantities are independent, or very nearly so. Hence, the covariances are zero or negligible.

[j] The response of pressurized ionization chamber A (PIC A) is determined from measurement of the time required to collect a given amount of charge on a stable fixed capacitor. All of the response measurements in the NIST pressurized ionization chambers are made relative to the response of one or more artifact standards. These artifact standards consist of microgram quantities of aged radium-226 in small welded stainless-steel capsules. These capsules are encapsulated in plastic rods whose dimensions are similar to those of the standard NIST ampoule. The artifact standards are called **Radium Reference Sources** and are designated as RRSx, where x is the nominal mass (in micrograms) of radium-226 in the capsule.

[k] The relative standard uncertainty of $\lambda \cdot t$ is determined by the relative standard uncertainty of λ (i.e., of the half life). The relative standard uncertainty of t is negligible.

[m] $|\partial y/\partial x_i| \cdot (x_i/y) = |\lambda \cdot t|$

[n] The live time is determined by counting pulses from a gated crystal-controlled oscillator.

[p] The standard uncertainty given is for the detected impurity. $|\partial y/\partial x_i| \cdot (x_i/y)$ = {(response per Bq of impurity)/(response per Bq of xenon-133)}$\cdot${(Bq of impurity)/(Bq of xenon-133)}.

[q] The standard uncertainty for each undetected impurity that might reasonably be expected to be present is estimated to be equal to the estimated limit of detection for that impurity, i.e. $u(x_i)/x_i$ = 100%. $|\partial y/\partial x_i| \cdot (x_i/y)$ = {(response per Bq of impurity)/(response per Bq of xenon-133)}$\cdot${(Bq of impurity)/(Bq of xenon-133)}. Thus, $u_i(y)/y$ is the relative change in y if the impurity were present with a massic activity equal to the estimated limit of detection.

REFERENCES

[1] International Organization for Standardization (ISO), *ISO Standards Handbook - Quantities and Units*, 1993. Available from Global Engineering Documents, 12 Inverness Way East, Englewood, CO 80112, U.S.A. Telephone 1-800-854-7179.

[2] International Organization for Standardization (ISO), *Guide to the Expression of Uncertainty in Measurement*, 1993 (corrected and reprinted, 1995). Available from Global Engineering Documents, 12 Inverness Way East, Englewood, CO 80112, U.S.A. Telephone 1-800-854-7179.

[3] B. N. Taylor and C. E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, 1994. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20407, U.S.A.

[4] Evaluated Nuclear Structure Data File (ENSDF), September 2005.